DYNAMICS OF BOUNDARY CURRENTS AND MARGINAL SEAS

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LONG-TERM GOALS

To describe and understand the dynamics of ocean circulation, with emphasis on western boundary current systems and interactions between the oceans and marginal seas.

OBJECTIVES

During the past year research was focused on observational studies of the exchange between the northwestern Indian Ocean and its bordering marginal seas: the Red Sea and the Arabian (Persian) Gulf. Extensive time series observations collected between May 1995 and November 1996 in the Bab el Mandeb (the strait connecting the Red Sea and the Gulf of Aden; Fig. 1), in collaboration with Dr. Steve Murray of LSU, were analyzed to determine the annual cycle of water exchange through the strait and the forcing factors responsible for seasonal and synoptic scale variability of the exchange. Exploratory time series observations in the Strait of Hormuz were also inititated in December 1996 to obtain a first direct measurement of the annual variation of deep outflow from the Persian Gulf to the Arabian Sea (Fig. 2).

APPROACH

Measurements collected in these programs consist of moored time series observations of currents, using profiling (ADCP) and conventional current meters, and of water properties using temperature/salinity chain arrays, complemented by seasonal hydrographic surveys and local meteorological and tide gauge measurements. In the Bab el Mandeb experiment, moorings were concentrated along two cross-channel arrays within the strait, located near the potential control sections, the "Perim narrows" (Section A) and "Hanish sill" (Section B; see Fig. 1). Three additional moorings were deployed in the descending plume region in the western Gulf of Aden. The cross-channel arrays were designed to measure the net inflow and outflow transports through the Strait, and to monitor the vertical structure of the exchange and its seasonal and shorter-term variability. The moorings along the western slope of the Gulf of Aden were designed to monitor the changing properties and intensity of the descending Red Sea water plume in response to variations in the deep outflow through the Strait. In the Strait of Hormuz, a pair of moorings was deployed at a single location near the center of the deep outflow channel to monitor the evolution of the inflow/outflow profile and the vertical watermass structure in the strait.

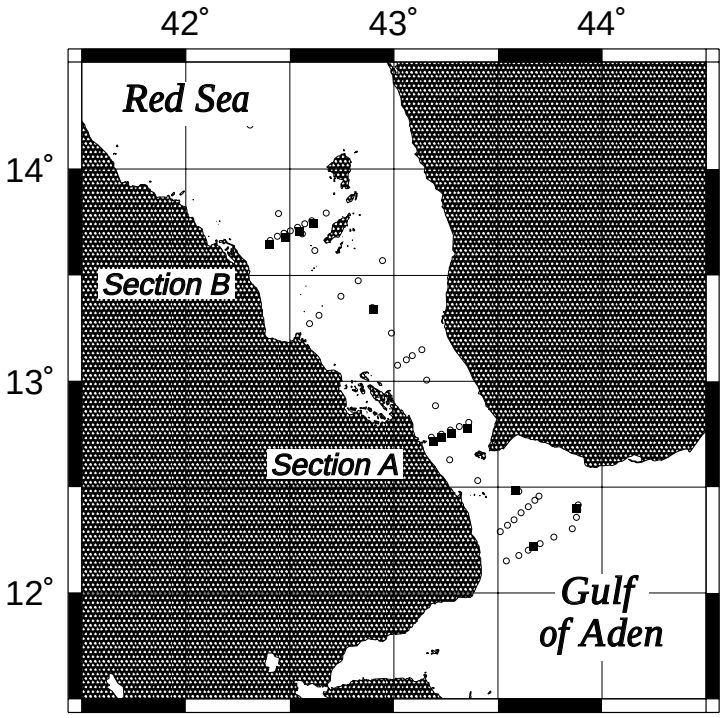

Figure 1: The Bab el Mandeb Strait. Squares indicate the locations of current meter moorings during the June 1996 - November 1996 measurement program; open circles show CTD station locations.

WORK COMPLETED

By November 1996 all mooring gear was retrieved from the Bab el Mandeb, including a total of 24 subsurface moorings (out of 25 that were deployed in two settings), 5 shallow pressure gauges, and an island meteorological station. Shipboard CTD/ADCP surveys of the strait region were conducted on three cruises in May-June 1995, March-April 1997, and November-December 1997. Processing of the project data is largely complete and a first paper on the results (Murray and Johns, 1997) has been produced. In the Strait of Hormuz, the first setting of moored equipment was deployed in December 1996, successfuly recovered in August 1997, and a second setting redeployed there for final retrieval in early 1998.

RESULTS

The 18-month measurement program in Babel Mandeb has confirmed earlier indirect estimates of an annual mean transport of approximately 0.3 Sv of Red Sea water through the Bab el Mandeb, with substantial seasonal variation ranging from more than 0.6 Sv in winter to nearly zero in late summer. Monsoon winds over the southern Red Sea and Gulf of Aden reverse from southeasterly in winter (November-April)

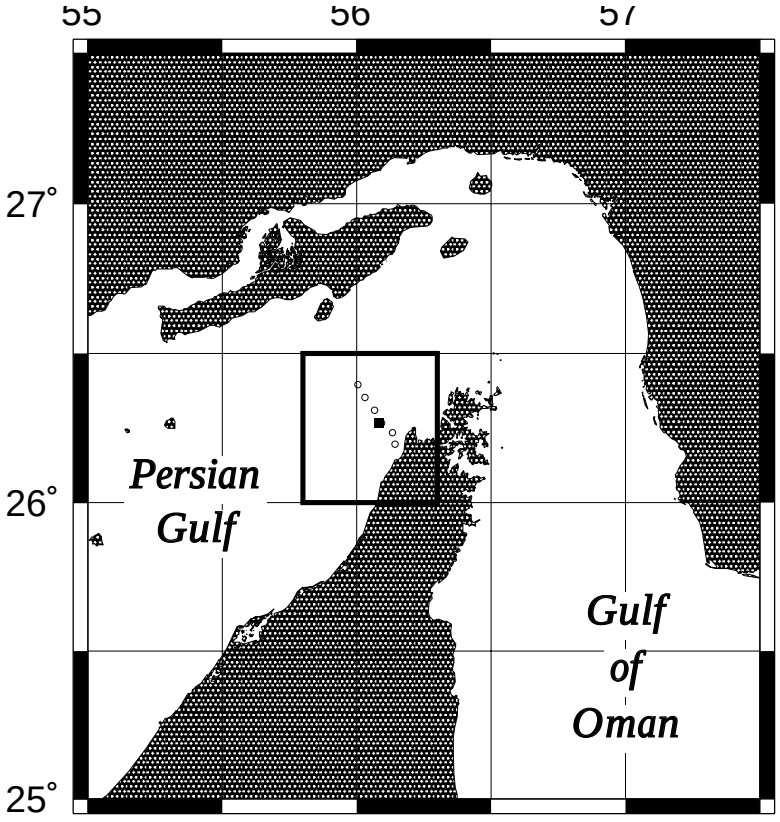

Figure 2: The Strait of Hormuz - the study region is in the deepest part of the strait off the northwestern Musandem Peninsula of Oman. The location of the ADCP/T-S chain mooring pair (square) and CTD stations (open circles) are indicated.

to northwesterly in summer (June-September), leading to strengthening and reinforcement of the two-layer thermohaline exchange during winter, and a three-layer exchange during summer consisting of weak surface and bottom outflows and an intermediate inflow. The inflow and outflow speeds appear to remain subcritical with respect to conditions for steady hydraulic control in the strait, even during maximum two-layer exchange flow in winter.

Synoptic transport variability through the strait on time scales from a few days to weeks is driven by two primary forcing mechanisms: wind stress variability over the strait, and variation in the large-scale barometric pressure over the Red Sea. Transport variations on these time scales can reach amplitudes of up to 0.6 Sv, nearly twice as large as the mean rate of exchange through the strait. Much of this synoptic variability can be explained by a linear, 2-layer model driven by the alongstrait wind stress and a barotropic alongstrait pressure gradient. With a resonable frictional parameterization, the main features of the forced response can be reproduced, including an elevated response amplitude near the Helmholtz period of the Red Sea at about 5

days.

Hydrographic and current meter measurements in the western Gulf of Aden show that the dense outflow from the Red Sea splits into two main branches just outside the strait, one running along a narrow deep channel in the northern Gulf of Aden and the second along a broader deep channel in the south. Both plume branches are seasonally active, but the northern branch is the preferred route during weak (summer) outflow. Volumetrically the southern branch is believed to be dominant pathway on an annual mean basis.

IMPACT/APPLICATIONS

This project has provided the first detailed, long-term measurements in the Bab el Mandeb, and should yield a new level of understanding of the exchange processes within the strait. A similar though less detailed understanding should be possible for the Strait of Hormuz, with focus on the deep outflow layer from the Persian Gulf. Comparative studies with other marginal sea straits (e.g., Gibraltar) will help to improve and broaden our understanding of the dynamical controls regulating ocean-marginal sea exchange.

TRANSITIONS

The data and results from these projects will transitioned to the Naval Oceanographic Office modeling group to provide accurate boundary conditions for their Red Sea and Persian Gulf models and for coupling of these models to the NRL Indian Ocean model.

RELATED PROJECTS

Cooperative work with ONR P.I. Larry Pratt (WHOI) on the hydraulic characteristics of the Bab el Mandeb flow as determined from the project data is underway. The structure of the Red Sea outflow plume in the western Gulf of Aden is being examined by combining the project data with AXBT survey data in the Gulf of Aden analyzed by ONR PI Amy Bower (WHOI). Analysis of the Strait of Hormuz moored time series data will be carried out in collaboration with U.K investigators Howard Roe and David Smeed, who have collected extensive shipboard survey data in the strait region during the period of the moored deployments.

REFERENCES

Murray, S.P. and W.E. Johns. 1997. Direct Observations of Seasonal Exchange through the Bab el Mandeb Strait. Geophys. Res. Lett. (in press).